iMAQ An Integrated Mobile Ad-hoc QoS Framework

Cross-Layer Design for Data Accessibility in Mobile Ad Hoc Networks

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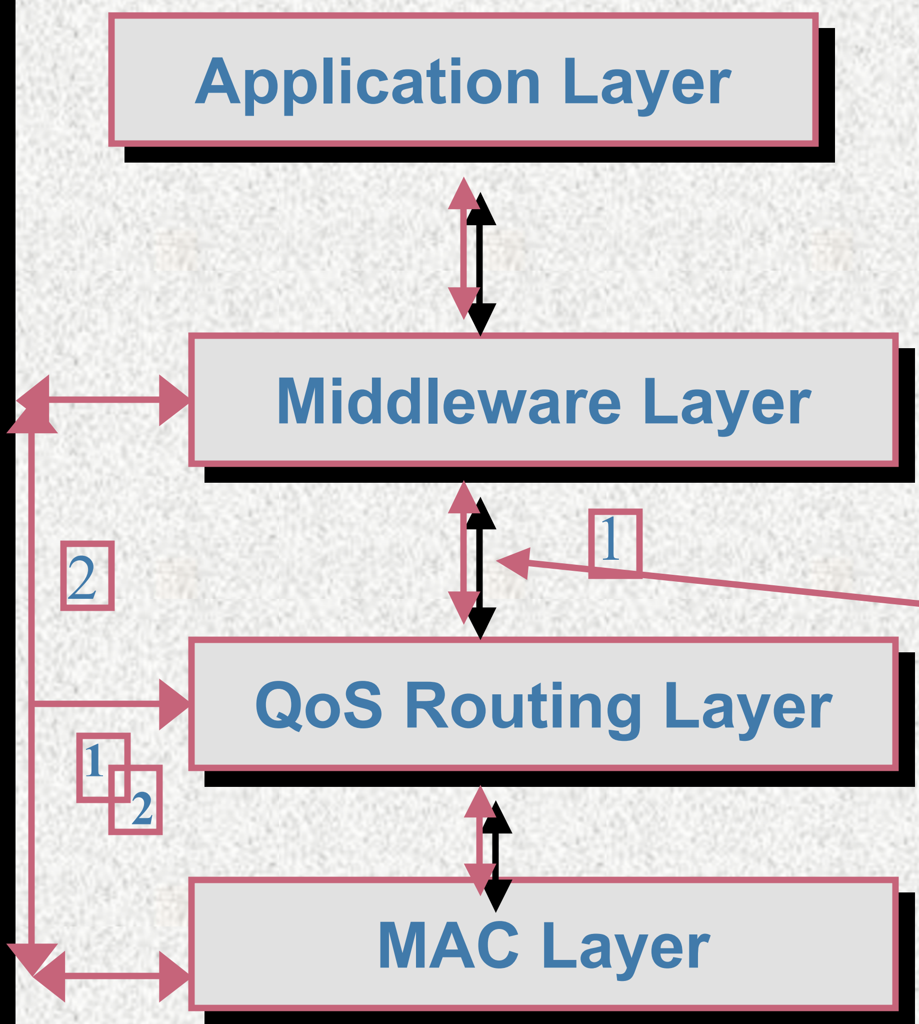
Cross-Layer Design



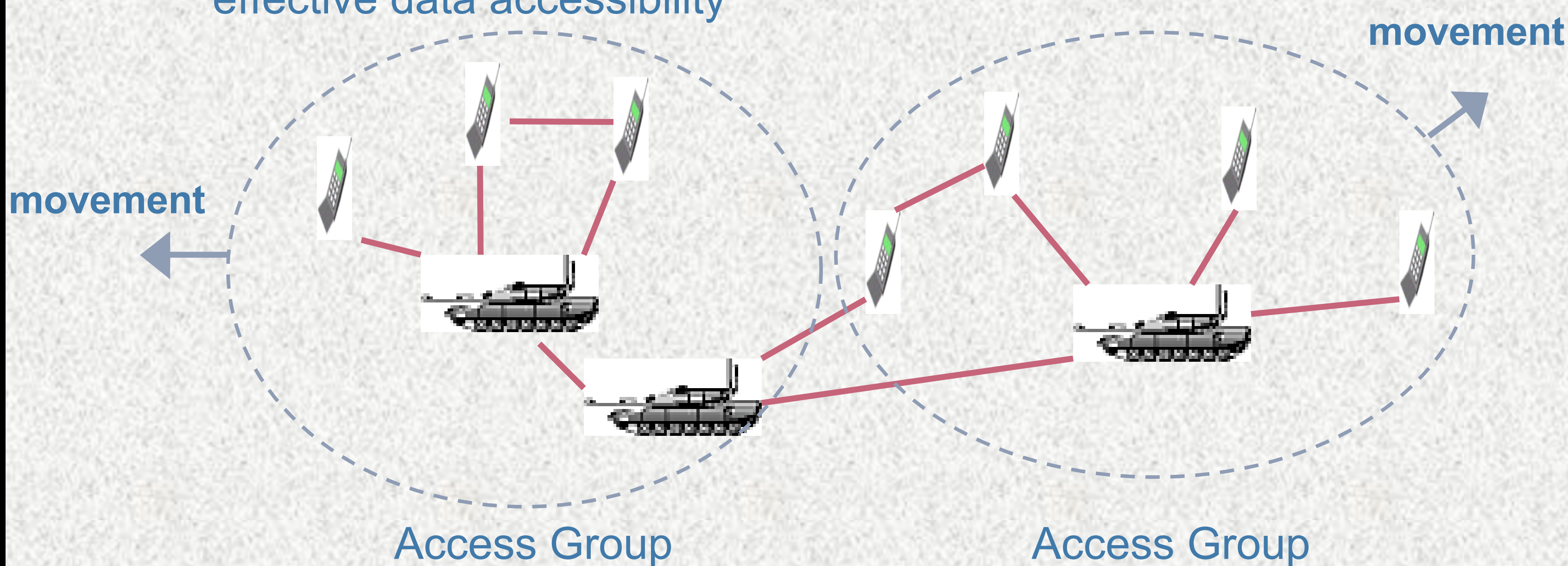
Cross-layer information

- Shares the state of the nodes such as location, resources, etc.
- QoS signaling between upper layer, routing layer, MAC for flow adaptations.

1. **Cross-Layer for Data Access**
2. Cross-Layer for Bandwidth Management

Cross-Layer for Data Accessibility

- **Scenario**
  - Mobile users create multimedia data and share them with others.
- **Problems**
  - Users should learn about each other's data and its location.
  - Network can become partitioned, which leads to missing data.
  - We need middleware services and routing services to collaborate for effective data accessibility

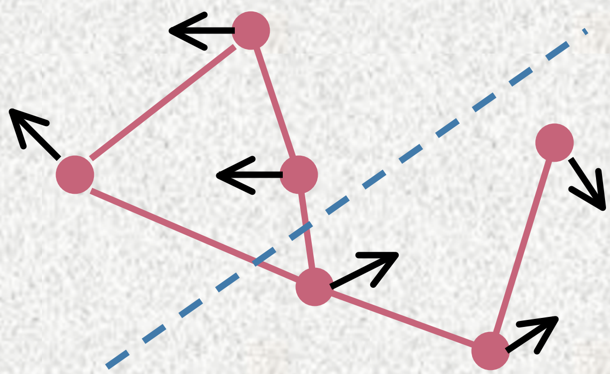


Data Advertising and Lookup
(Middleware Services)

- **Advertising message**
  - ➔ Broadcasted from each node periodically
    - Let other nodes learn about its data and location.
    - Rate adaptation based on the size of the group for scalability.
  - ➔ Format
    - Node info: <sender_address, free_space, power_left, etc.>
    - List of data: <data_id, data_description>
- **Data availability lookup table**
  - ➔ Each node derives the table from the advertising messages.
  - ➔ Format: list of <data_id, data_description, data_locations>
  - ➔ Soft-state: each entry has to be refreshed otherwise data is inactive.

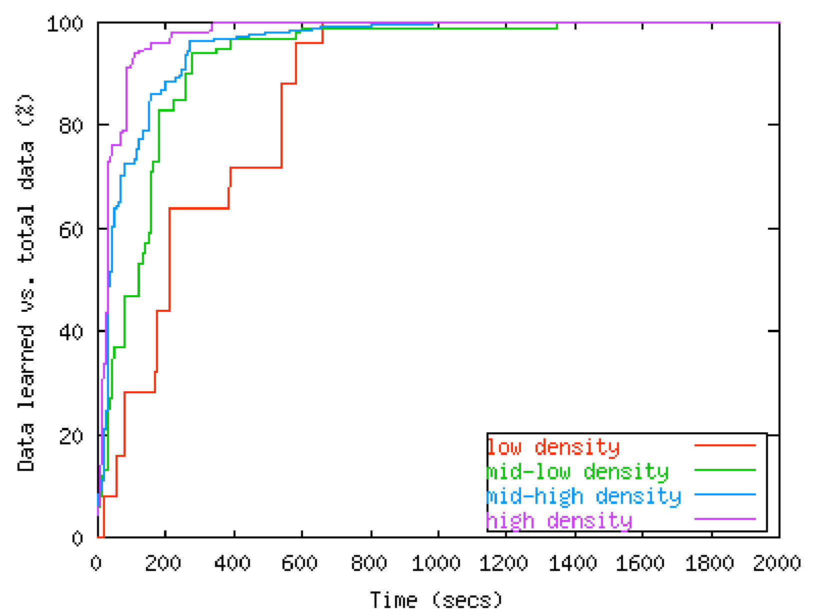
Predictive Data Replication

- **Predict group partitioning**
  - **Obtain information** from the **predictive location-based routing layer**
    - Each node's location, movement, and transmission range.
  - **Linear motion prediction** of group partitioning
  - **Replicate data** to the other partitions
    - Before group partitioning occurs
    - Selects the best destination based on the capability of the nodes.

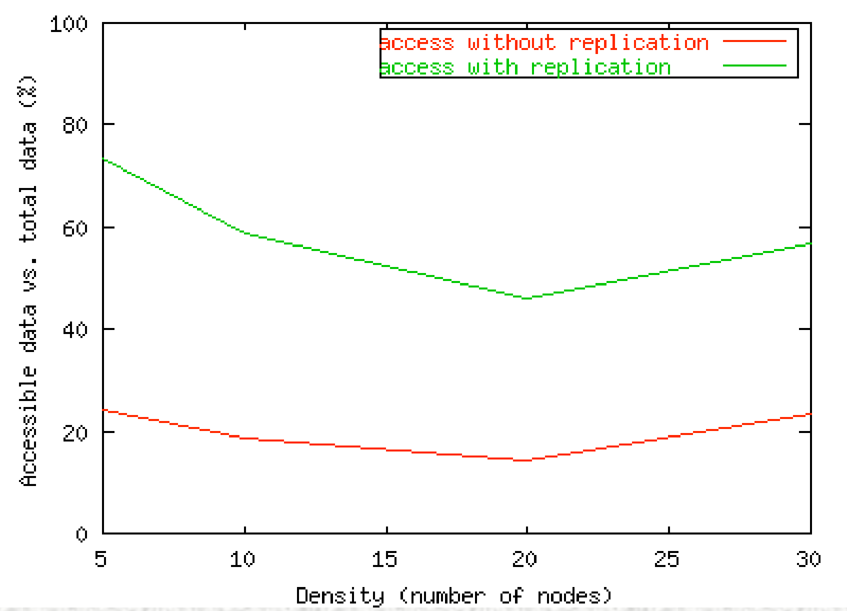


Partitioning will occur here.

Data Accessibility Results

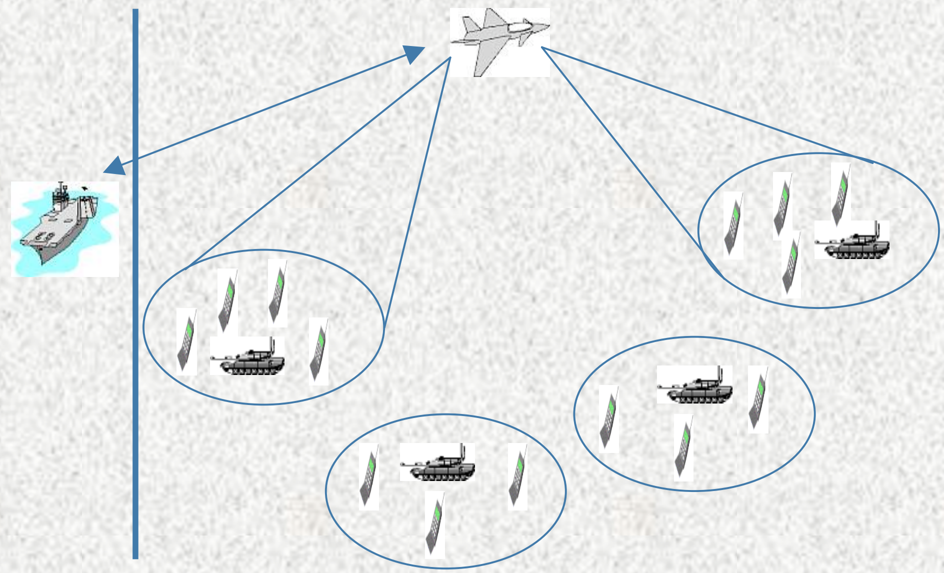


Comparison of data availability information based on advertising.



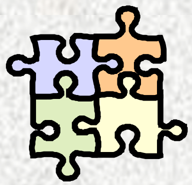
Comparison of data accessibility based on replication.

Routing Service



QoS Routing is **difficult**:

1. Locations may change
2. Resource availability can vary
3. Routes become obsolete quickly
4. Heterogeneous nodes and links



Solution:

Predictive Location-based QoS Routing

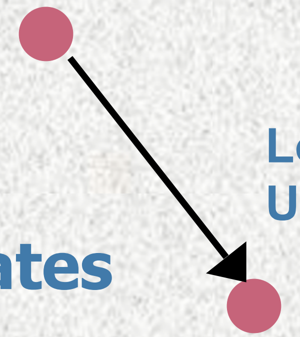
Location-Resource Updates

- **Updates** flooded over the network
  - **Message Format**: <timestamp, co-ordinates, direction of motion, velocity, resource information, motion stability parameter>
  - **Resource information**: battery power, queuing space, transmission range, etc.
  - **Motion stability**: probability of continuing its motion pattern
- **Updates** are generated
  - **Type I**: periodically with period varying with velocity or distance
  - **Type II**: if there is a change in the pattern of motion

Predictions

--- based on the

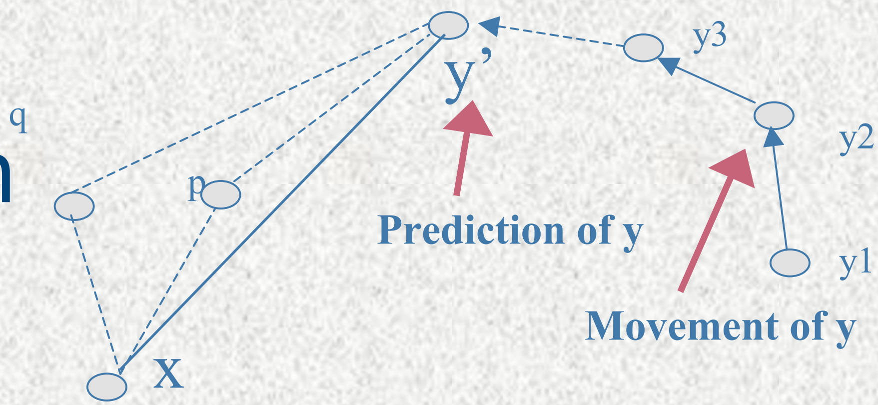
location-resource updates



Location-resource Updates Received

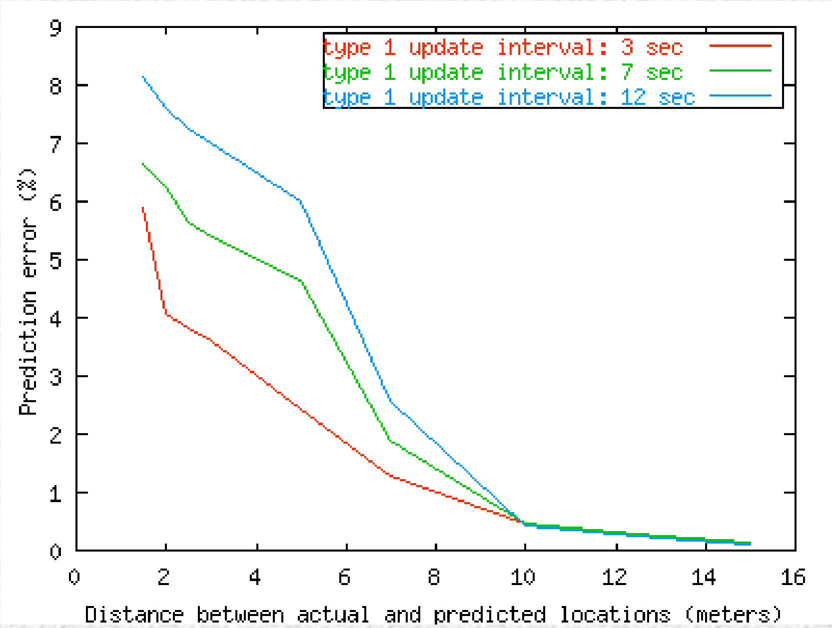
- **End-to-end delay** in reaching other nodes is predicted based on the end-to-end delay experienced by their recent updates.
- **Prediction of location** of the receiving node is needed at the instant it is to receive the packet.
  - For nodes moving along a straight line, **one previous update** is sufficient.
  - For nodes moving along an arc, **three previous updates** are required to fit a curve to the arc and predict future location.
- Resource info in the updates is used to compute a **cost function** used in **admission control** which proceeds hand-in-hand with route computation.

Route Computation

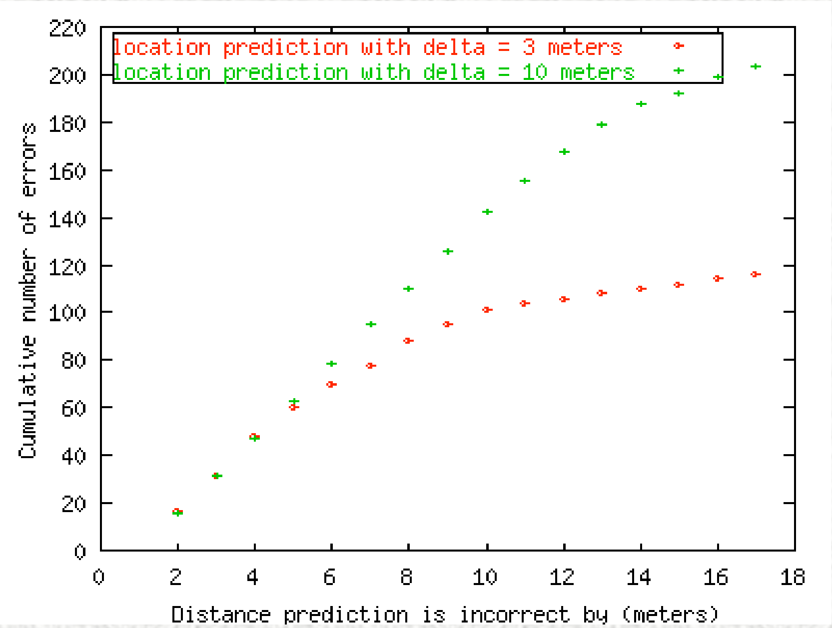


- **Protocol:**
  - <u>*Source x*</u> finds
    - » Which of its neighbors has **sufficient resources** to satisfy the QoS requirement of the connection, and the node lies **closest to the destination (y)** at the time of receiving the packet
  - If there is no such candidate, then reject connection! Else, choose this node as next <u>*hop p*</u>
  - Repeat the above from *p* until <u>*destination y*</u> is reached (source routing)
  - QoS route is now established
  - At every future update, check if the route is about to be broken
    - » If some node is going to move out of the range of its next hop neighbor, re-compute route using above mechanism.
  - If a future update indicates degradation in resource availability, re-compute route.

Results of Location-Resource Updates

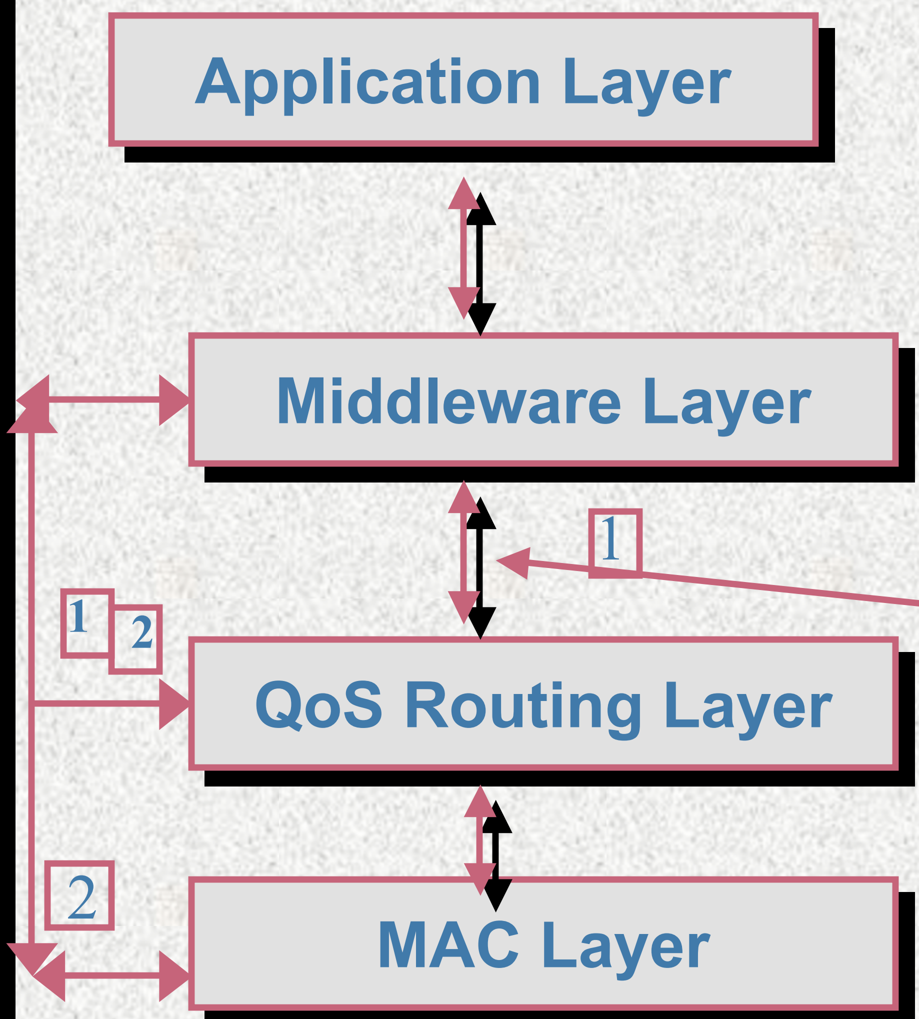


Accuracy of location + delay prediction for various type I inter-update intervals.



Comparison of cumulative prediction errors with different location deviations in type II updates.

Cross-Layer Design



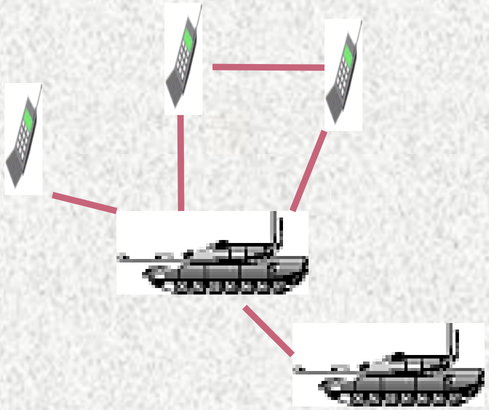
Cross-layer information

- Shares the state of the nodes such as location, resources, etc.
- QoS signaling between upper layer, routing layer, MAC for flow adaptations.

1. Cross-Layer for Data Access
2. **Cross-Layer Bandwidth Management**

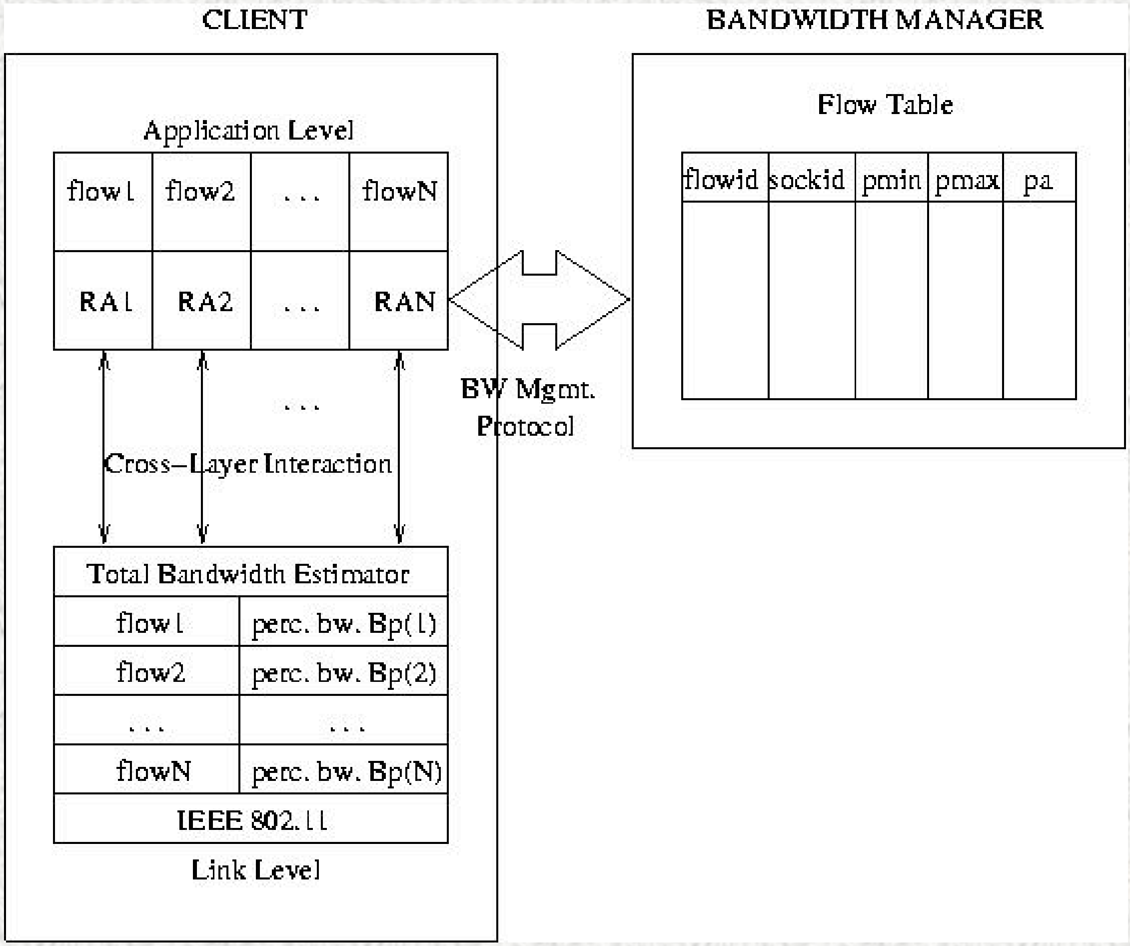
Cross-Layer Bandwidth Management

- **Scenario**
  - Mobile nodes share multimedia data in a single-hop environment.
- **Problems**
  - Wireless channel is shared, hence to achieve predictive bandwidth allocation for multimedia data is difficult
  - We need middleware services and MAC services to collaborate for effective bandwidth allocation



Access Group

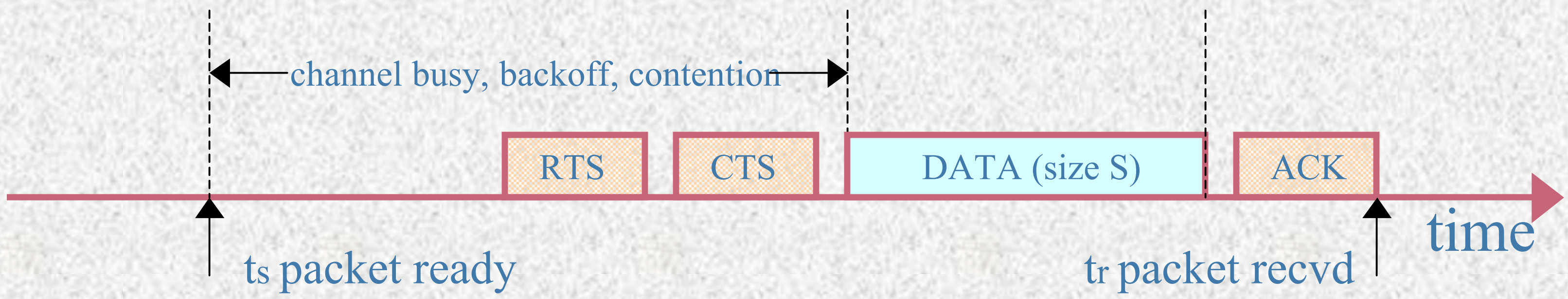
Bandwidth Management Architecture



Total Bandwidth Estimator (TBE)
(MAC Service)

- Per-node, link level measurement, for every flow originating at this node
- Measure continuously the total perceived bandwidth $B_p(f)$ for each flow
- If $B_p(f)$ changes, RA of f renegotiates channel time proportion of f
- Take average over a period fed back to RAs through /proc interface
- Take into account contention for medium and errors causing re-xmit

Bandwidth Estimation



- Measured BW= $S/(t_r - t_s)$
  - Running average with decay/Average over an interval
  - More contention? More time channel sensed as busy, more RTS/CTS collisions, higher backoffs => BW estimate smaller
  - More channel errors? Bit-errors in RTS/DATA cause RTS/DATA retransmission => BW estimate smaller
  - Only successfully transmitted MAC frames used in estimate

Rate Adaptor
(Middleware Service)

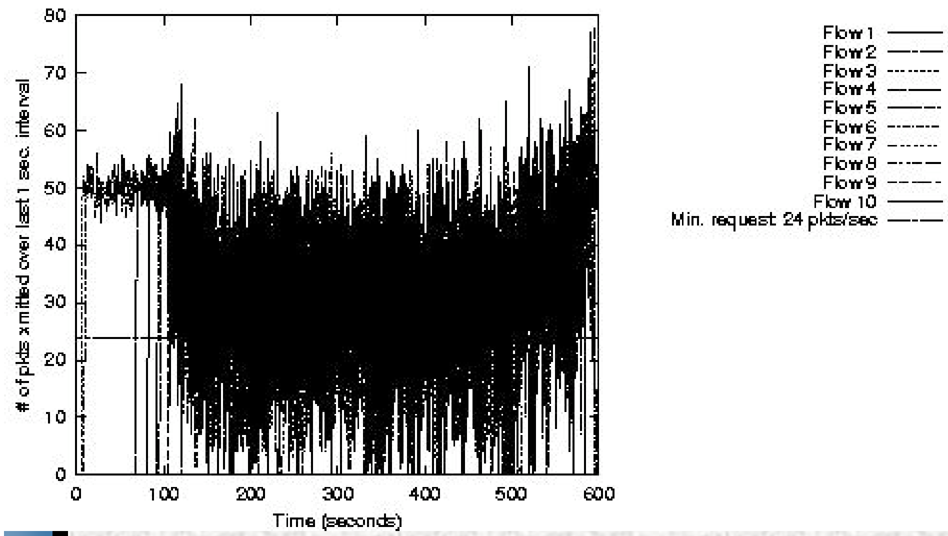
- Per-flow
- Obtain max. and min. bandwidth requirements ($B_{max}(f)$ and $B_{min}(f)$) from flow
- $p_{max}(f) = B_{max}(f) / B_p(f)$: Max. channel time proportion $p_{max}(f)$
- $p_{min}(f) = B_{min}(f) / B_p(f)$: Min. channel time proportion $p_{min}(f)$
- Channel time proportion (CTP): what fraction of unit time does this flow "own" the channel?
- Send CTP requirements to BM
- Receive reply containing CTP granted $p_a(f)$
- Transmission rate = $p_a(f) * B_p(f)$ bits per sec.

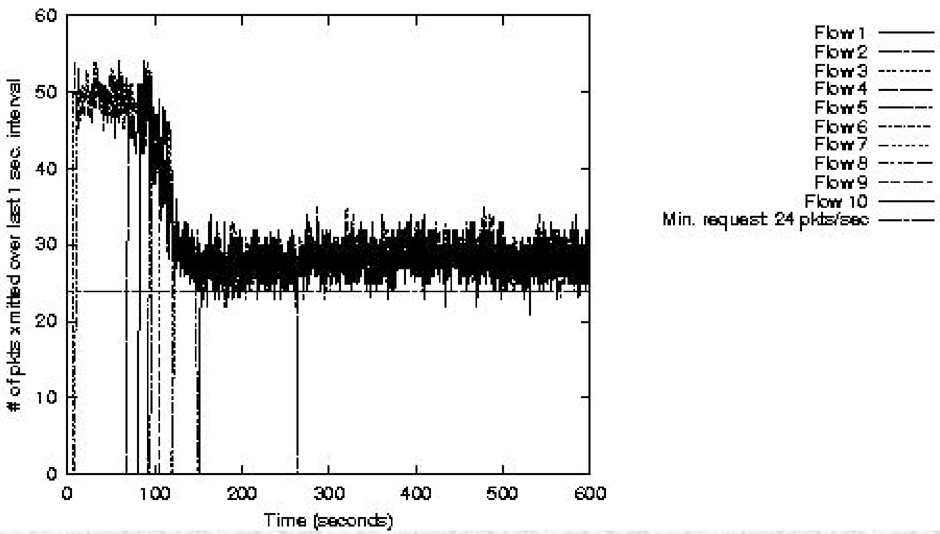
Bandwidth Manager
(Middleware Service)

- Admission Control:
  - for all flows *g* in the set of previously registered flows
    - » *If* $1-\_{g} p_{min}(g) \geq p_{min}(f)$ *true,* then admit flow *f*, else reject
- Once *f* is admitted BM redistributes channel time within the new set of admitted flows, i.e., $p_{rem}=1-\_{f} p_{min}(f)$ for all admitted *f* must be fairly re-distributed

Performance Results using Simulation

- Scenario 1: 25 nodes, 10 CBR flows
- Maximum requirement 200kbps (~48pkts/s)
- Minimum requirement 100kbps (~24pkts/s)
- 33% loss rate with base 802.11
- 8% lesser overall throughput using bandwidth management





Conclusion and Contacts

Summary

- MAC, Routing and middleware benefit from **cross-layer design**, sharing location, QoS, etc., due to avoidance of work duplication.
- QoS routing shows feasible results when using **predictive location-based routing protocol**.
- Data accessibility improves significantly with **predictive replication**.
- Data quality improves significantly with **MAC-aware bandwidth management**

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- Project/Publications URL: http://www-monet.cs.uiuc.edu/adhoc

Publications on Cross-Layer

- Kai Chen, Samarth Shah, Klara Nahrstedt, "*Cross-Layer Design for Data Accessibility in Mobile Ad-hoc Networks*", **Wireless Personal Communications Journal**, Kluwer Academic Publisher, Special Issue on Multimedia Network Protocols and Enabling Radio Technologies, July 2001, Vol. 21, No. 1, pp. 49-76.
- Kai Chen, Yuan Xue, Samarth Shah, Klara Nahrstedt, *"Understanding Bandwidth-Delay Product in Mobile Ad Hoc Networks"*, **Elsevier Computer Communications Journal**, Special Issue on Protocol Engineering for Wired and Wireless Networks, Peter Langendoerfer, Vassilis Tsaoussidis (Guest Editors), to appear in 2004
- Samarth Shah, Kai Chen, Klara Nahrstedt, *"Dynamic Bandwidth Management in Single-hop Ad hoc Wireless Networks"*, **ACM/Kluwer MONET (Mobile Networks and Applications Journal)**, Special Issue on Algorithmic Solutions for Wireless, Mobile, Ad Hoc and Sensor Networks, vol. 10, No. 1, pp. ?-?, February 2005.
- Kai Chen, Klara Nahrstedt, "*An Integrated Data Lookup and Replication Scheme in Mobile Ad-Hoc Networks*", **SPIE Electronic Imaging - Optoelectronic and Wireless Data Management, Processing, Storage and Retrieval**, Vol. 4534, November 2001, pp. 1-8.

Publications on Cross-Layer

- Kai Chen, Klara Nahrstedt, "*Effective Location-guided Tree Construction Algorithms for Small Group Multicast in MANET*", **IEEE INFOCOM 2002,** New York, NY, June 2002, pp. 1180-1189
- Samarth Shah, Kai Chen, Klara Nahrstedt, "*Dynamic Bandwidth Management in Wireless LANs*", **IEEE International Conference on Pervasive Computing and Communications (PerCom) 2003**, Forth Worth, TX, March 2003
- Samarth Shah, Kai Chen, K. Nahrstedt, "Available Bandwidth Estimation in IEEE 802.11-based Wireless Networks (Extended Abstract)", Proceedings of **1st ISMA/CAIDA Workshop on Bandwidth Estimation (Best 2003**), San Diego, CA, December 2003
- Kai Chen, Klara Nahrstedt, Nitin Vaidya, *"The Utility of Explicit Rate-Based Flow Control in Mobile Ad Hoc Networks"*, accepted to **IEEE Wireless Communications and Networking Conference (WCNC 2004)**, 2004

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- (*w) Samarth Shah, Kai Chen, K. Nahrstedt, *"Price-based Channel Time Allocation in Wireless LANs"*, **IEEE Mobile Distributed Computing (MDC 2004),** workshop associated with ICDCS 2004, Tokyo, Japan, 2004
- (*w) Kai Chen, K. Nahrstedt, *"iPass: an Incentive Compatible Auction Scheme to Enable Packet Forwarding Service in MANET"*, **IEEE International Conference on Distributed Computing Systems (ICDCS 2004)**, Tokyo, Japan, March 2004.
- Samarth Shah, Klara Nahrstedt, "*Predictive Location-based QoS Routing in Mobile Ad-Hoc Networks*", **IEEE International Conference on Communications (ICC) 2002,** New York, April 2002
- Samarth Shah, Klara Nahrstedt, "'Channel-Aware Throughput Fairness in Multi-Cell Wireless LANs", **VTC'F04 Wireless Personal Communication Systems,** 2004
- Yuan Xue, Kai Chen, Klara Nahrstedt, *"Proportional Delay Differentiation in Wireless LAN"*, **IEEE International Conference on Communications (ICC 2004),** Paris, France, June 2004